AD

DRSAR/PE/N-82

PROGRAM ANALYSIS AND EVALUATION DIRECTORATE

ACTIVITIES SUMMARY

SEPTEMBER 1979

Approved for public release; distribution unlimited.

US ARMY ARMAMENT MATERIEL READINESS COMMAND

PROGRAM ANALYSIS AND EVALUATION DIRECTORATE

ROCK ISLAND, ILLINOIS 61299

DISPOSITION

Destroy this report when no longer needed. Do not return it to the originator.

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position.

WARNING

Information and data contained in this document are based on input available at the time of preparation. Because the results may be subject to change, this document should not be construed to represent the official position of the US Army Materiel Development & Readiness Command unless so stated.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER DRSAR/PE/N-82	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Program Analysis and Evaluation Directorate Activities Summary		5. TYPE OF REPORT & PERIOD COVERED Note - Final 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Armament Materiel Readiness Command Program Analysis and Evaluation Directorate Rock Island, IL 61299		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Materiel Readiness Command Program Analysis and Evaluation Directorate Rock Island, IL 61299		12. REPORT DATE Sep 1979 13. NUMBER OF PAGES 59
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Additions or deletions of addresses to/from the DISTRIBUTION LIST are invited and should be forwarded to address below. Inquiries pertinent to specific items of interest may be forwarded to Commander, US Army Armament Materiel Readiness Command, ATTN: DRSAR-PE, Rock Island, IL 61299, AUTOVON 793-5075/5930.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Technical Data Package (TDP)
Procurement Work Directive (PWD)
Administrative Lead Time (ALT)
Procurement Lead Time (PROLT)
Production Lead Time (PLT)
Chemical Agent Evaporation Rates
Authorized Acquisition Objective (AAO)
Approved Distribution Objective (ADO)
Theater Combat Rate
Basic Load
(see back)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report contains Memoranda for Record (MFR's) that summarize activities of the Program Analysis and Evaluation Directorate, US Army Armament Materiel Readiness Command, Rock Island, IL 61299. Subjects dealt with are: Cost Impact of Increased Procurement Lead Times for Secondary Items; Calculating Evaporation Rates from Chemical Agent Spills; Ammunition Requirements Terminology; Continuous-Process Facilities Cost as a 2/3 Power Function of Capacity; TDP's of $2500 and Less.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19. Key Words:
Required Supply Rate (RSR)
Available Supply Rate (ASR)
2/3 Power Function Rule

TABLE OF CONTENTS

Memorandum for Record

EVIDENCE FOR CONTINUOUS-PROCESS FACILITIES COST AS A 2/3 POWER FUNCTION OF CAPACITY

George Schlenker

DRSAR-PEL 09 JAN 1979

MEMORANDUM FOR RECORD

SUBJECT: Evidence for Continuous-Process Facilities Cost as a 2/3 Power Function of Capacity

1. References:

a. MFR, DRSAR-PEL, 20 Sep 78, subject: Study of Policy Alternatives for Inactive Ammunition Production Facilities.

b. Technical Report No. AMSAR/SAO/R-10, Aug 75, title: A Supplementary RDX/HMX Products Site Selection Study--Economic Cost Analysis.

c. Article in Scientific American, Jan 79, p. 77, title: Coal Oil to KWH.

2. Decision rules concerned with management of production facilities generally involve the cost (or price) of production capacity (C_e) and the unit cost of the product (C_a). A key parameter is the ratio of capacity cost to unit product cost. This parameter is called the relative cost of capacity and is denoted by κ, measured in units of time. This quantity represents the time required for the facilities operating a capacity to produce a product equal in value to that of the plant. An example of a decision rule in which the quantity κ plays a key role is given in Ref 1a. This pertains to maintenance of inactive ammunition production facilities. Another decision involving κ is the stockpile versus production capacity tradeoff in the logistics of ammunition items.

3. For industrial plants producing a bulk product using a continuous process conventional wisdom has it that the cost of capacity is not a constant value, independent of capacity, but rather depends upon

capacity. Chemical engineering handbooks often present cost estimating formulas for process equipment which display cost of capacity as a power function of capacity. This implies that the total cost of facilities (C_{fac}) for that process is a power function of the capacity (r).

4. An application of this form of cost estimating relationship is provided in Ref 1b in which the cost of facilities for making explosives by a continuous process is assumed to follow a 0.6 power law. However, one may ask how valid is such a scaling law when applied to other continuous processes.

5. It is the purpose of this memorandum to indicate the existence of data for another type of continuous process plant the cost of which is consistent with a 2/3 power law. The data is presented in a short article in Scientific American magazine (Ref 1c) in connection with the production of liquid fuel via hydrogenation of coal.

6. Ashland Oil Co. (with collaborators) has made engineering estimates for the cost and capacity of a pilot plant, currently under construction in Catlettsburg, Ky. These data represent a relatively low-capacity operation. Ashland has also provided a cost estimate for a plant having about 50 times the capacity of the pilot plant. Similarly the Exxon Corp. has estimated the cost of a large scale plant of comparable capacity which employs a somewhat different process. These data are presented in Table 1.

7. It is noteworthy that the Ashland expanded H-coal plant and the Exxon "pioneer" plant have nearly the same value of κ -- 37 versus 38 months, probably within the estimation error. Because of its much lower capacity the pilot plant has a much larger value of κ -- 128 months.

TABLE 1

FACILITIES COST AND CAPACITY DATA FOR THE PRODUCTION OF FUEL OIL FROM COAL BY HYDROGENATION

Facility	Cost of Facility, C_{fac} (\$) estimated by producer	$\hat{C}_{fac}$ (\$) (Note 1)	Estimated Capacity, r (bbl/day)	Price of Capacity, C_e (\$/bbl/day)	Relative Price of capacity, κ (mo) (Note 2)
Ashland Oil H-coal pilot plant in Catlettsburg, Ky.	$1.0 \quad 10^8$	$0.95 \quad 10^8$	$1.3 \quad 10^3$ (750-1800)	$7.7 \quad 10^4$	128
Ashland Oil Expanded H-coal plant	$1.1 \quad 10^9$	$1.10 \quad 10^9$	$5 \quad 10^4$	$2.2 \quad 10^4$	37
Exxon "pioneer" EDS hydrogenation process plant	$1.4 \quad 10^9$	$1.24 \quad 10^9$	$6 \quad 10^4$	$2.3 \quad 10^4$	38

Note 1. $\hat{C}_{fac} = 7.8 \quad 10^5 \quad r^{0.67}$ with r in bbl/day

Note 2. $\kappa = C_e/C_a$ with C_a = \$20/bbl. This quantity is the time required to produce a product whose value equals the replacement value of the facility.

0 9 JAN 1979

DRSAR-PEL
SUBJECT: Evidence for Continuous-Process Facilities Cost as a 2/3 Power Function of Capacity

8. To demonstrate the consistency of these data with the 2/3 power rule, a facility cost $\hat{C}_{fac}$ is provided for comparison with C_{fac} in which $\hat{C}_{fac}$ is calculated as a 2/3 power of capacity, r. The coefficient in this formula was obtained by fitting the data for the Ashland H-coal plant. Note from Table I that the values of $\hat{C}_{fac}$ are quite close to C_{fac} for the other two plants. The capacity of the H-coal pilot plant used in this calculation is the average of the values given, rounded to two significant figures.

9. Altho agreement between these facility cost estimates is excellent, the results should be regarded as indicative rather than a definitive proof of the 2/3 power rule for this class of production facility.

George Schlenker

GEORGE SCHLENKER
Operations Research Analyst

Memorandum for Record

IMPACT OF INCREASED LEAD TIMES FOR SECONDARY ITEMS: A COST ESTIMATE FOR ARRCOM

Norman Trier

DRSAR-PES

0 8 MAY 1979

MEMORANDUM FOR RECORD

SUBJECT: Impact of Increased Lead Times for Secondary Items: A Cost Estimate for ARRCOM

1. This MFR will demonstrate that increased lead times do result in higher operating costs for ARRCOM. First, a detailed example for one item is presented (paragraph 2) to show the effects of increased lead times. Then a method to determine the cost impacts to ARRCOM for all items is discussed (paragraph 3). Finally, ARRCOM data is presented, and the estimated cost of increased lead times is determined (paragraphs 4 and 5).

2. An example: In order to understand the impact of increased lead times, the following example is presented:

Given a part which has a unit price (UP) = $1.38, an average monthly demand (AMD) = 334 with variance = x, and an availability = 99.3%.

Determine what happens when the above data remains constant, but the procurement lead time (PROLT = ALT + PLT) increases from 7 months to 14 months.

Through the use of ARTIS, the above given data was input into a model which simulates the CCSS system. The following values for safety levels and reorder cycles were obtained:

PROLT	7 Months	14 Months
Safety Level	6.9 Months (2.30K pieces)	13.9 Months (4.64K pieces)
Reorder Cycle	11.4 Months (3.81K pieces)	11.6 Months (3.87K pieces)

As can be seen, when PROLT increases, both the safety stock level and reorder cycle increase. The two cases were plotted (see Figure 1 and 2) so that the higher operating levels can be seen. The following values are extracted from the graphs:

FIGURE 1. Inventory Position of Item When PROLT = 7 Months (An Example)

Case 1: S.L. = 6.9 mo = 2.30K pieces
L = 7 mo = 2.34K pieces
Q = 11.4 mo = 3.81K pieces
R.O. = S.L. + L + Q = 8.46K pieces

① Ave qty on hand = S.L. + Q/2 = 4.21K pieces

② Ave qty on hand + on order = S.L. + Q/2 + L = 6.55K pieces

③ Ave qty on order = ② - ① = 2.34K pieces

RWP = S.L. + L = 4.64K pieces

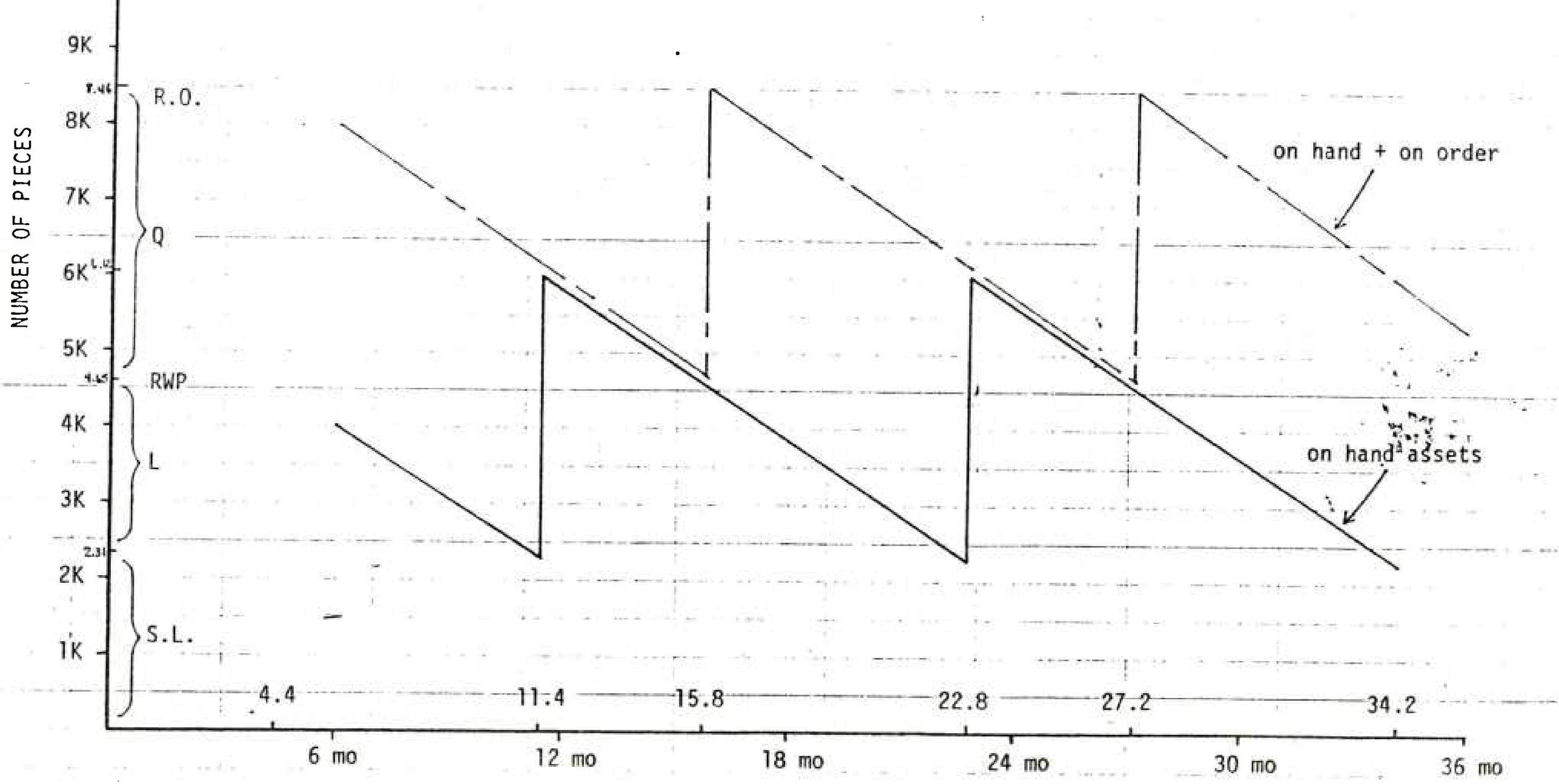
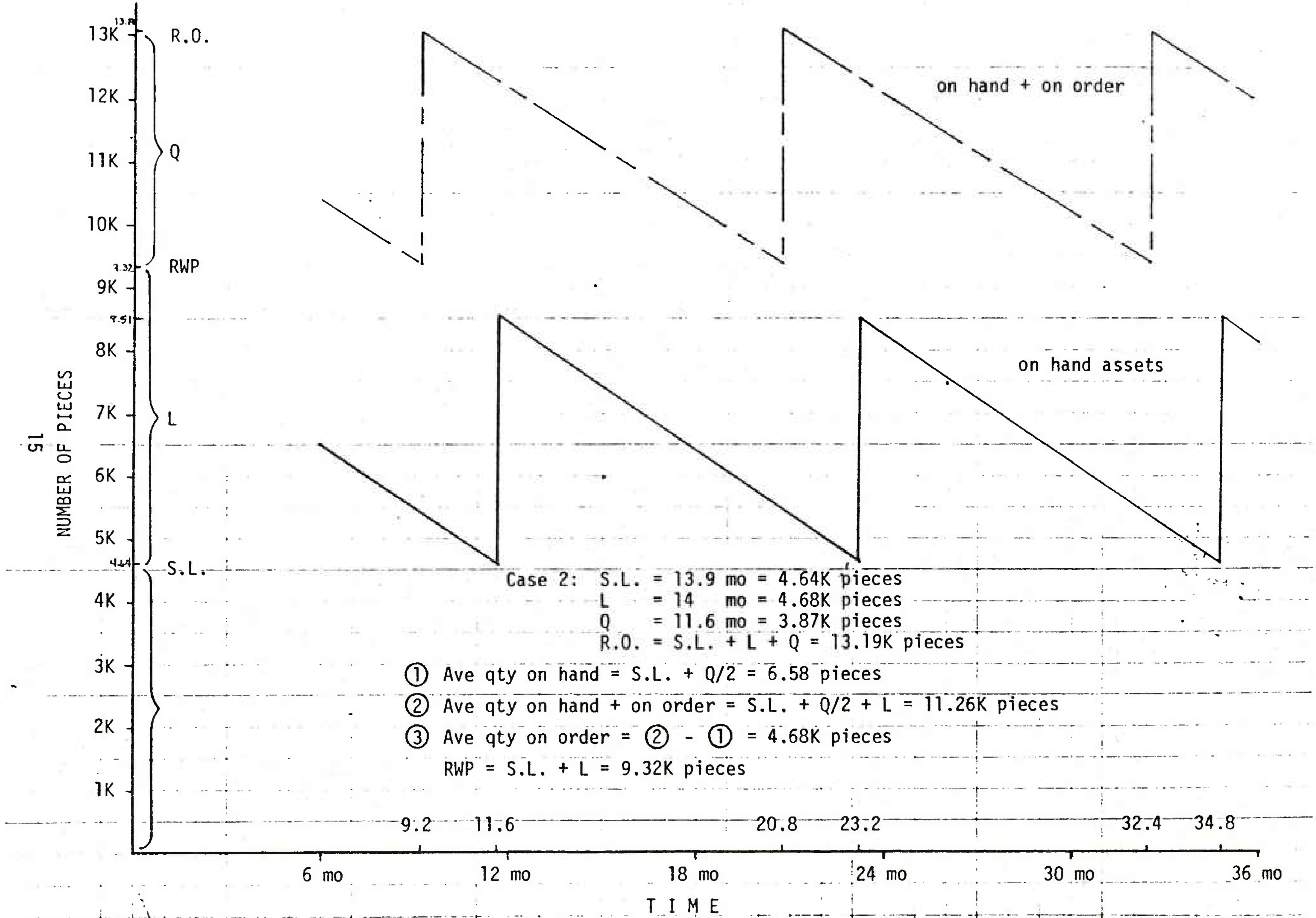


FIGURE 2. Inventory Position of Item When PROLT = 14 Months (An Example)



		Case 1	Case 2	Δ Increase
1.	PROLT	7 Months	14 Months	7 Months
2.	Safety Level (SL)	2.30K pieces	4.64K pieces	2.34K pieces
3.	Lead Times Demands (L)	2.34K pieces	4.68K pieces	2.34K pieces
4.	Order Quantity (Q)	3.81K pieces	3.87K pieces	0.06K pieces
5.	Ave Quantity on hand + on order (SL + Q/2 + L)	6.55K pieces	11.26K pieces	4.71K pieces

With this information the following can be said:

a. Increases in lead times cause increases in operating levels (i.e., the average quantity on hand plus on order increased 4.71K pieces for this item).

Notice that this increased operating level is equal to $SL_\Delta + Q_\Delta/2 + L_\Delta$, where, for example, $SL_\Delta = 4.64K - 2.30K = 2.34K$ pieces.

The increased operating level consists of two parts:

a. Increased average quantity on hand $(SL_\Delta + Q_\Delta/2)$.

b. Increased average quantity on order (L_Δ).

The dollar values of these are, respectively,

a. $(SL_\Delta + Q_\Delta/2) \times (UP) = (2.34K + .06K/2) \times (\$1.38/\text{piece}) = \$3.27K$

b. $(L_\Delta) \times (UP) = (2.34K \text{ pieces}) \times (\$1.38/\text{piece}) = \$3.23K$

This means that an additional $3.27K are invested in increased on hand assets and that an additional $3.23K are invested in increased lead time demands.

It would seem logical, then, that there is a cost associated with maintaining these increased quantities on hand and on order.

To gain insight to this, consider the total variable cost (TVC) equation which is used in the CCSS. The following equation was extracted from C12, AR 710-1, pg 4-17:

$$TVC=\sum_{i=1}^{n} AD_i/Q_i+\sum_{i=1}^{n} IC_i(R_i+Q_i/2)+\left(\begin{array}{l}\text{implied customer}\\\text{shortage cost}\end{array}\right)*\left(\begin{array}{l}\text{time weighted, essentiality}\\\text{weighted, requisitions short}\end{array}\right)$$

where

A = order cost

D_i = mean annual demand quantity for ith item

Q_i = order quantity for ith item

I = holding cost rate (percentage)

C_i = cost of ith item

R_i = reorder warning point (RWP_i) of the ith item

= mean lead time demands (L_i) plus safety level (SL_i)

For the purposes of this analysis, the last term will not be included in the following equations since it deals mainly with the cost of back orders. Through substituting and factoring, it follows that:

$$TVC = \sum_{i=1}^{n} AD_i/Q_i + \sum_{i=1}^{n} IC_i\ (R_i + Q_i/2)$$

$$= \sum_{i=1}^{n} AD_i/Q_i + \sum_{i=1}^{n} IC_i\ (L_i + SL_i + Q_i/2)$$

$$= \sum_{i=1}^{n} AD_i/Q_i + \sum_{i=1}^{n} IC_i\ (SL_i + Q_i/2) + \sum_{i=1}^{n} IC_i\ (L_i)$$

where

$SL_i + Q_i/2$ = average on hand assets of ith item

L_i = mean lead time demands of ith item

As was found above, when lead times increase, the safety level and leadtime demands increase. If we assume that each Q_i remains constant, then the increased total variable costs (TVC_Δ) due to increased lead times would be:

$$TVC_\Delta = \sum_{i=1}^{n} IC_i\ (SL_{\Delta_i}) + \sum_{i=1}^{n} IC_i\ (L_{\Delta_i})$$

This means that the cost of increased lead times can be estimated by applying a holding cost rate (23% is used at ARRCOM) to the dollar value of the increased on hand assets and increased quantities on order.

However, consider that ARRCOM's holding cost rate (23%) consists of the following parameters:

a. Investment cost rate (10%) which is the discount rate that covers the cost of capital.

b. Obsolescence risk rate (8%) which covers losses caused by technological improvements, over forecasting of requirements, etc.

c. General storage cost rate (2%) covers the costs of clerical, administrative and variable storage space costs and the expense of taking physical inventories.

d. Storage loss rate (1%) and deterioration rate (2%) which covers the cost due to pilferage, shrinkage, inventory adjustments, etc.

After considering these factors, it was decided that for the purposes of this analysis, the holding cost rate of 23% was applied to the dollar value of increased on hand assets, and that only the investment cost rate (10%) plus the obsolescence risk rate (8%) was applied to the dollar value of increased quantities on order. This was done since it appears that the general storage cost rate (2%), the storage loss rate (1%) and the deterioration rate (2%) should be applied only to on hand assets.

Therefore, for this example, the costs incurred would be as follows:

a. Increased holding cost = (23%) X ($3.27K) = $752/year

b. Increased investment cost = (10%) X ($3.23K) = $323/year

c. Increased obsolescent cost = (8%) X ($3.23K) = $258/year

d. Total increased annual cost = ($752/year) + ($323/year) + ($258/year) = $1,333/year

This means the increased lead times for this item resulted in an increased annual cost = $1,333/year. This cost will be incurred as long as operation at the higher level continues.

3. Method: From the example in paragraph 2, it was shown that increased lead times resulted in increased dollar values of the quantities on hand (\$ value of $SL_{\Delta} + Q_{\Delta}/2$) and in increased dollar values of the quantities on order (\$ value of L_{Δ}). Once these increases were quantified, the cost of increased lead times could be determined by applying a holding cost rate to the increased \$ value of on hand assets and an investment cost rate plus an obsolescence risk rate to the increased \$ value of quantities on order.

An estimate of the \$ value of SL_{Δ} and L_{Δ} for ARRCOM was obtained by following the procedure below. With these values, the cost of increased lead times can be determined as stated above. This estimate will be somewhat conservative since it will not include an estimate of the increased \$ value of $Q_{\Delta}/2$ (the average increased stock on hand due to increased order quantities).

To estimate the cost of increased lead times at ARRCOM, the following procedure can be used (details will be explained in the next paragraph as the procedure is applied to actual data):

a. Obtain the following data from outputs of previous Budget Stratification runs for Army Stock Fund (ASF) and PAA secondary items:

	Months (\$ Weighted)	\$ Value
Safety Level (SL)		
Administrative Lead Time (ALT)		
Production Lead Time (PLT)		

These data are the sum of all ARRCOM items in that group.

b. For each Budget Stratification, combine ASF and PAA values to determine total values (months and \$ values) for SL, ALT, PLT, and PROLT (ALT + PLT).

c. Use historical inflation factors to convert original year dollars to constant FY79 dollars so that the values are comparable.

d. Plot the dollar value of assets versus the quarterly time periods corresponding to the Budget Stratification runs for SL, ALT, PLT, and PROLT.

e. Perform a least squares linear regression and plot the regression line obtained for SL, ALT, PLT, PROLT.

f. For a specific time period, extract the dollar values from the regression lines for SL, PLT, ALT, and PROLT and determine the following increases in dollar value for that period of time: (1) \$ value of SL_Δ; (2) \$ value of L_Δ for ALT; (3) \$ value of L_Δ for PLT; and (4) \$ value of L_Δ for PROLT.

g. The cost of increased lead times can now be estimated by applying the holding cost rate to the increased dollar value of the safety level stock (\$ value of SL_Δ) and by applying the investment cost rate plus an obsolescence risk rate to the increased dollar value of the quantities on order (\$ value of L_Δ for PROLT). If one wishes to identify the portion of costs associated with ALT increases, then simply apply the opportunity cost rate plus the obsolsecence risk rate to the increased dollar value of L_Δ for ALT; do likewise for PLT.

4. Analysis: To estimate the cost of increased lead times at ARRCOM, the procedure described in paragraph 4 will be followed.

a. The data extracted from previous Budget Stratifications are displayed in Table 1. Just as a matter of interest the values for \$ weighted months are also presented in the data tables.

b. Since the data was separate for ASF and PAA items, these items were combined to get total values for Secondary Items. These combined values are displayed in Table 2 along with an additional column for PROLT (ALT + PLT).

c. The historical inflation multipliers used in this analysis are displayed in Table 3. These multipliers converted the original year dollars to constant FY79 dollars. Table 4 displays the data in FY79 dollars.

d. Plots of the dollar value of assets versus the quarterly time periods for SL, ALT, PLT, and PROLT are shown in Figure 3.

e. A least squares linear regression was performed on the values for SL, ALT, PLT, and PROLT, and resulted in the following equations:

TABLE 1.

Data Extracted From Various Summary Dollar Stratifications for ARRCOM Under A) Opening Position

	ALT		PLT		SL	
Date of Budget Strat	Months ($ Weighted)	$ Val ($ $\bar{M}$)	Months ($ Weighted)	$ Val ($ $\bar{M}$)	Months ($ Weighted)	$ Val ($ $\bar{M}$)
31 Dec 78						
Total	6.5	142	12.5	225	2.9	47
30 Sep 78						
ASF	5.4	111.4	11.7	176.7	2.5	30.1
PAA	7.0	28.9	12.8	39.7	1.8	5.8
30 Jun 78						
ASF	5.3	99.3	12.1	178.2	4.3	53.1
PAA	5.3	23.7	12.3	45.1	2.3	6.3
31 Mar 78						
ASF	5.5	86.8	12.1	169.2	4.1	46.7
PAA	5.2	20.9	12.8	45.7	2.0	6.0
31 Dec 77						
ASF	5.0	86.2	11.6	155.5	2.3	25.1
PAA	5.4	17.9	12.8	41.9	2.0	5.1
30 Jun 77						
ASF	4.4	100.0	11.1	159.5	2.0	22.6
PAA	4.2	26.2	13.0	42.9	1.7	4.5
31 Mar 77						
ASF	4.4	76.6	11.4	154.2	2.3	20.6
PAA	4.3	17.0	12.5	36.3	2.1	4.2
30 Sep 76						
ASF	3.9	51.2	11.1	111.3	5.6	17.3
PAA	4.3	8.5	11.1	29.6	5.9	3.2
30 Jun 76						
ASF	3.7	46.1	12.3	155.5	6.1	21.4
PAA	4.0	8.9	11.6	27.2	6.0	3.9
30 Jun 75						
ASF	4.1	50.9	11.7	127.4	2.1	15.4
PAA	4.9	7.8	11.9	17.2	2.8	3.7
30 Jun 74						
ASF	3.7	40.6	11.6	106.2	4.0	23.7
PAA	3.7	7.7	10.9	20.7	4.4	6.3

TABLE 2.

ARRCOM's Secondary Items
Data Compiled From Quarterly Strat Runs (In Original Year Dollars)

	ALT		PLT		PROLT		SL	
	Months ($ Weighted)	$ $\bar{M}$	Months ($ Weighted)	$ $\bar{M}$	Months ($ Weighted)	$ $\bar{M}$	Months ($ Weighted)	$ $\bar{M}$
31 Dec 78	6.5	142	12.5	225	19.0	367	2.9	47
30 Sep 78	5.7	140	11.9	216	17.6	356	2.4	36
30 Jun 78	5.3	123	12.5	216	17.8	339	6.8	36
31 Mar 78	5.4	108	12.2	215	17.6	323	3.9	53
31 Dec 77	5.1	104	11.9	197	17.0	301	2.2	30
30 Jun 77	1.2	126	11.5	202	12.7	328	2.0	27
31 Mar 77	4.4	94	11.6	191	16.0	285	2.3	25
30 Sep 76	4.0	60	11.1	141	15.1	201	5.6	21
30 Jun 76	3.7	55	12.2	183	15.9	238	6.1	25
30 Jun 75	4.2	59	11.7	145	15.9	204	2.2	19
30 Jun 74	3.7	48	11.5	127	15.2	175	4.1	30

TABLE 3.

Inflation Indicies and Their Application

A. Historical inflation multipliers[a] to convert original year dollars to FY78 dollars for "combined ordance and accessories" are 1.53 for FY74, 1.33 for FY75, 1.22 for FY76, 1.17 for FY7T, and 1.10 for FY77.

B. The inflation multiplier[b] to convert FY78 dollars to FY79 dollars is 1.068.

C. Historical inflation multipliers to convert original year dollars to FY79 dollars (combination of A and B above), which are used in this analysis, are as follows:

FY74	1.634	FY7T	1.250
FY75	1.420	FY77	1.175
FY76	1.303	FY78	1.068

D. The inflation multipliers which were applied to the dollar values from the various strats are shown below. When the strat was run on the last day of a fiscal year, the inflation multiplier for the next year was applied.

31 Dec 78	1.0	31 Mar 77	1.175
30 Sep 78	1.0	30 Sep 76	1.175
30 Jun 78	1.068	30 Jun 76	1.250
31 Mar 78	1.068	30 Jun 75	1.303
31 Dec 77	1.068	30 Jun 74	1.420
30 Jun 77	1.175		

[a]Reference Incl 1 of DRSAR-CPE DF, 17 Apr 79, subject: Inflation Guidance.

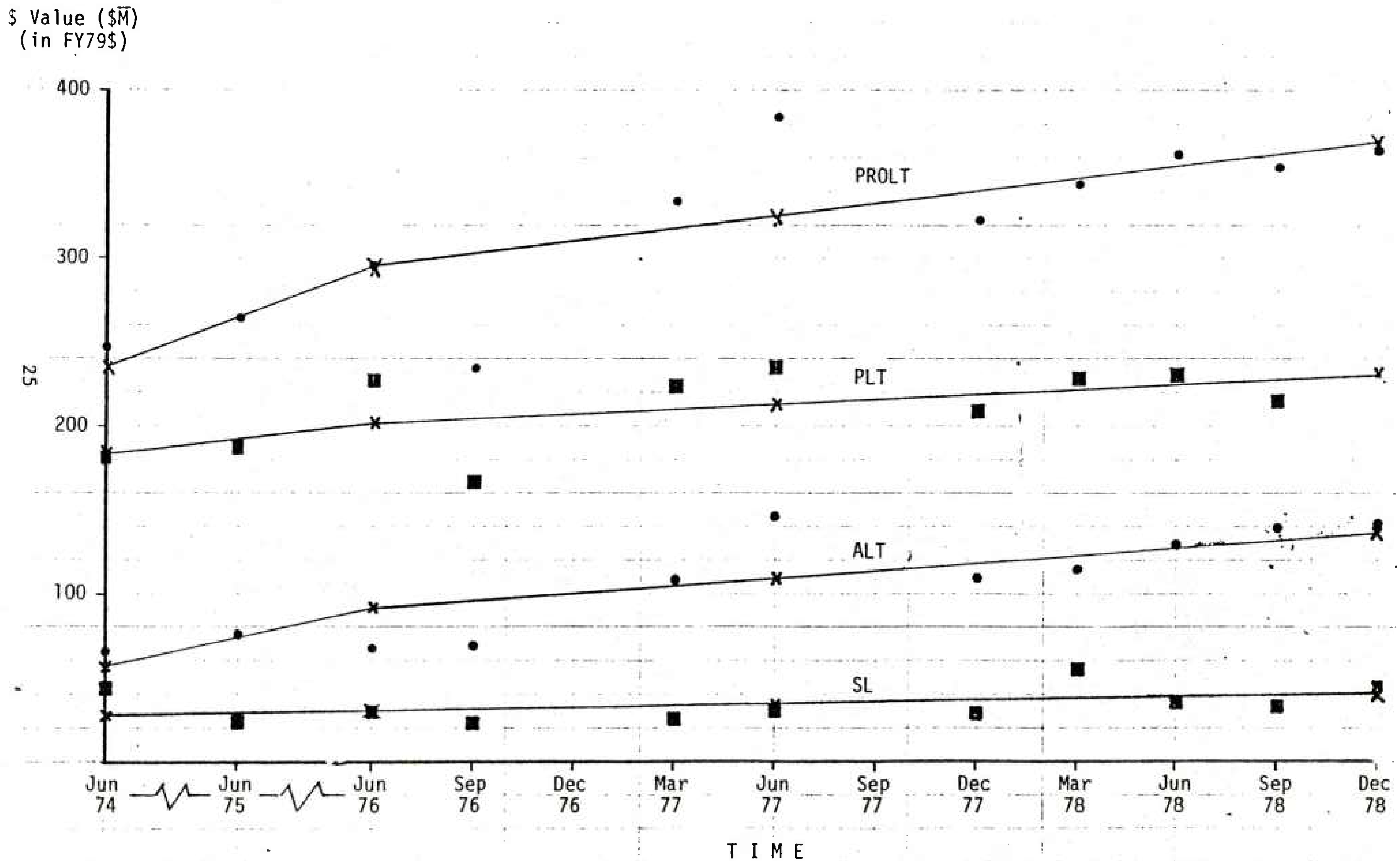
[b]Reference Incl 6 of DRSAR-CPE DF, 8 Sep 78, subject: Inflation Guidance.

TABLE 4.

ARRCOM's Secondary Items
Data Compiled From Quarterly Strat Runs (FY79 $)

	ALT		PLT		PROLT		SL	
	Months ($ Weighted)	$ $\bar{M}$	Months ($ Weighted)	$ $\bar{M}$	Months ($ Weighted)	$ $\bar{M}$	Months ($ Weighted)	$ $\bar{M}$
31 Dec 78	6.5	142	12.5	225	13.0	367	2.9	47
30 Sep 78	5.7	140	11.9	216	17.6	356	2.4	36
30 Jun 78	5.3	131	12.5	231	17.8	362	6.8	38
31 Mar 78	5.4	115	12.2	230	17.6	345	3.9	57
31 Dec 77	5.1	111	11.9	210	17.0	322	2.2	32
30 Jun 77	1.2	148	11.5	237	12.7	385	2.0	32
31 Mar 77	4.4	110	11.6	224	16.0	335	2.3	29
30 Sep 76	4.0	71	11.1	166	15.1	236	5.6	25
30 Jun 76	3.7	69	12.2	229	15.9	297	6.1	31
30 Jun 75	4.2	77	11.7	189	15.9	266	2.2	25
30 Jun 74	3.7	68	11.5	180	15.2	249	4.1	43

FIGURE 3. Plot of the Dollar Value of Assets (in FY79 $) Versus Time



$ value of SL ($\bar{M}$) = 0.604X + 28.5 with the correlation coefficient (r)=.35

$ value of L for ALT ($\bar{M}$) = 4.625X + 50.7 with r = .83

$ value of L for PLT ($\bar{M}$) = 2.683X + 179.5 with r = .64

$ value of L for PROLT ($\bar{M}$) = 7.298X + 230.4 with r = ..81

where

X = the number of quarters from time zero which commences from 4th quarter FY73 (e.g., at 4th quarter FY73, X = 1; and at 1st quarter FY79, X = 19).

These equations were plotted on Figure 3 and should demonstrate the increasing trends of the dollar value of assets.

f. For this analysis, the two year period from Sep 76 through Sep 78 was considered. Values at the beginning and ending of the two year period were calculated from the regression lines, and the increased dollar value of assets were determined. Values obtained (in FY79 dollars) were:

	30 Sep 76	30 Sep 78	Δ Increase
SL	35\bar{M}$	39\bar{M}$	4\bar{M}$
ALT	97\bar{M}$	134\bar{M}$	37\bar{M}$
PLT	206\bar{M}$	228\bar{M}$	22\bar{M}$
PROLT (ALT + PLT)	303\bar{M}$	362\bar{M}$	59\bar{M}$

g. The cost (in FY79 dollars) to ARRCOM due to increased lead times can now be determined as follows:

Annual Holding Cost = (holding cost rate) X ($ value of SL_{Δ})

= (.23/year) X (4\bar{M}$)

= 0.92\bar{M}$/year

Annual Investment Cost = (opportunity cost rate) X ($ value of L_{Δ} for PROLT)

= (.10/year) X (59\bar{M}$)

= 5.9\bar{M}$/year

Annual Obsolescence Risk Cost = (obsolescence risk rate) X ($ value of L_Δ for PROLT)

= (.08/year) X (59\bar{M}$)

= 4.7\bar{M}$

Total Increased Annual Cost = 0.9\bar{M}$/year + 5.9\bar{M}$/year + 4.7\bar{M}$/year

= 11.5\bar{M}$/year

5. Summary: It was demonstrated that increased lead times result in increased quantities on hand ($SL_\Delta + Q_\Delta/2$) and on order (L_Δ) and that the annual cost of these higher operating levels is determined by applying a holding cost rate to the increased dollar value of on hand assets and by applying an opportunity cost rate plus an obsolescence risk rate to the increased dollar value of quantities on order.

The dollar values for increased quantities on hand and on order for all ARRCOM managed secondary items can be approximated by using available data from previous budget stratification runs.

It was determined that the approximate cost (in FY79 dollars) to ARRCOM due to increased lead times over the period of 30 Sep 76 to 30 Sep 78 are as follows:

Increased Annual Holding Cost = 0.9\bar{M}$/year

Increased Annual Investment Cost = 5.9\bar{M}$

Increased Annual Obsolescence Risk Cost = 4.7\bar{M}$

Total Increased Annual Cost = 11.5\bar{M}$/year

ARRCOM will incur this loss each year while continuing to operate at the higher levels of lead time.

Norman H. Trier

NORMAN H. TRIER
Operations Research Analyst
Systems Assessment Division
Program Analysis & Evaluation Directorate

Fact Sheet

AMMUNITION

REQUIREMENTS

TERMINOLOGY

William Shore

FACT SHEET
(ARRCOMM 340-1)

TO: DRSAR-DCG	FROM: DRSAR-PE	DATE: 3 May 1979
		WRITER/PHONE EXT: W.S. SHORE/6583

SUBJECT

Ammunition Requirements Terminology

PURPOSE

To provide DCG with definition and analysis of ammunition requirements terminology and practice in response to DCG Note PE-13 dated 15 Febuary 1979.

FACTS

1. Reference is made to DCG Note PE-13, dated 15 February 1979 (TAB A).

2. Program Analysis and Evaluation Directorate in consultation with the Defense Ammunition Directorate should develop a simple comparison of, and a relationship between the terms (AMMO only) as follows: AAO, ADO, Theater Combat Rates (P-Rates and D-Rates), Basic Load, RSR, and ASR.

(a) Definitions:

(1) AAO (Authorized Acquisition Objective): "The quantity of materiel authorized for peacetime acquisition to equip the U.S. Army approved forces and specified allies in peacetime and to sustain these forces in wartime from D-Day through the period and at the level of support prescribed by the latest DOD guidance. Units of measure: numbers of items... The AAO is the gross requirement less production offset." (Reference: AR 700-120.)

(2) ADO (Approved Distribution Objective): "Quantities required to support current or projected Army and specified allied forces through prescribed periods. ADO's address capability forces and available munitions." (Reference: HQDA, DAMA-CSM, in a briefing at the Ammunition Quarterly Review, Dec. 1977.)

(3) Theater Combat Rate: "A quantity of ammunition per day which, when multiplied by an authorized number of days, will produce a stock level of conventional ammuition that is required to support forces in combat, conduct training activities, and compensate for losses due to enemy action or losses in transit until such a time as normal supply can be effected: (Reference: (C) SB-38-26, "Ammunition Combat Rates (U)" 25 September 1972.)

(4) Basic Load: "The quantity of conventional ammunition authorized by major commanders to be on hand in units and which is carried by the individual or on the unit vehicles at all times to enable the unit to accomplish its mission until normal resupply can be effected. (The basic load is continuously reconstituted as used.)" (Reference: (C) SB-38-26, 25 September 1972.)

(5) RSR, "Required Supply Rate": The amount of ammunition expressed in terms of rounds per weapon per day for ammunition items fired by weapons, estimated to be required to sustain operations of any designated force without restriction for a specified period. (Reference FM 101-10-1 "Staff Officer's Field Manual, Organizational, Technical and Logistics Data", dated February, 1978.)

(6) ASR, "Available Supply Rate": Officially; "ammunition available supply rate," changed to "Ammunition Controlled Supply Rate" (CSR): "The amount of ammunition estimated to be available to sustain operations of a designated force for a specified time if expenditures are controlled at that rate. It is expressed in terms of rounds per day for ammunition items fired by weapons. (Reference: AR 310-25, "The Army

Dictionary".)

(b) Given the agreed definitions the relationships and assumptions are as follows:

(1) AAO and ADO - ("Army [Approved] Distribution Objective - ADO) will specify requirements in terms of current munitions, while the end of the POM period requirement (Army [Authorized] Acquisition Objective - AAO) will be stated as a mix of new ammunition items which are scheduled to be deployed in that time frame along with the existing rounds expected to be in the inventory." (Reference: Annex D, Army Ammunition Plan, October 1978.)

(2) Theater Combat Rates are generated in two types - (1) D-Rates for current weapons and munitions and used to compute the ADO's and (2) the P-Rates for the mix of weapons and munitions at the end of the POM period and used to compute the AAO's.

(3) Basic Load - Part of the post D-Day consumption component of the AAO and represents a demand on the distribution system rather than a quantitative requirement. (Reference: "Army Command and Management: Theory and Practice, Textbook Army War College, Carlisle Barracks, PA, 1977-1978.)

(4) Required Supply Rate - That deemed necessary to support combat, derived from the SB 38-26 theater combat rates or recent experience (not limited by the supply system).

(5) Controlled Supply Rates - Allocates on a divisional level existing assets according to immediate need up to the RSR (may be limited by the supply system).

(c) What are the Parameters? AAO and ADO - (Theater Combat Rate [TCR] X Weapons Density [WD] X Days of Combat) in a theater plus all other war requirements. For the AAO, TCR is the P-Rate, WD is the end of POM condition, and the days of combat are specified in the Consolidated Guidance, summed over all theaters. For the ADO TCR is the D-Rate (SB-38-26), WD is for current conditions and the days are specified in AR 11-11 by theater.

(d) What are the Usages? "The AAO is the programing requirement and is basis for the Army's Procurement Programs and is used to justify budgets and programs submitted to OSD/OMB and congress. The ADO is equal to the distribution requirement and is "[the] (a) basis for determining theater war reserve levels authorized by AR 11-11 and for validating requisitions [from the field], (b) as a guide for computing resupply of active overseas commands, and (c) as a guide for establishing initial stockage and resupply in a newly activated theater." (Reference AR 710-8.)

(e) What are the Omissions? None that we are aware of.

(f) What is the effect on buying ammo? AAO - Controls the total ammunition program for the FYDP. ADO - Directs ammunition materiel which theaters may requisition by specified fiscal years to train and fight in the near term.

DRSAR-PE
SUBJECT: Ammunition Requirements Terminology

(g) What should be changed?

(1) Standardize and control usage of terms. Specifically, formalize the definition of the ADO.

(2) Improve planning so that there is a smooth change from the ADO to the AAO while maintaining desired readiness.

(h) How we draw down inventory of old items:

We stop buying; i.e., eliminate the item from the AAO, and dispose of the stocks by use or sale.

3. References consulted are listed in Tab B.

M. Rhian

M. RHIAN
Director
Program Analysis & Evaluation Directorate

2 Incl
as

COMMAND GROUP ACTION

NOTE: ____________________

SEE ME: ____________________

CF:
DRSAR-LC, Mr. Ambrosini

CONCURRENCE:

DRSAR-DA Concur
Concur/~~Nonconcur~~ Robert R Haws 4 May 1979

TAB B

REFERENCES

(1) Letter from DAMA-PPP-P entitled "Guidelines for Preparation of the FY81-85 POM Procurement Programs"; 19 Dec 1978, Washington, D.C. See Procurement Planning and Guidance.

(2) AR 350-50 Army Abbreviations and Acronyms, 1975.

(3) AR 310-25 Army Dictionary, 1977.

(4) DARCOM Data Element Dictionary, 1 January 1979.

(5) JCS Pub 1 Dictionary of Military and Associated Terms, 1974.

(6) AR 710-1 Centralized Inventory Management of the ArmySupply System C16 Dated 18 March 1977 with TWX changes through Jun 1978.

(7) AR 11-11 Major Command Stockage Levels Worldwide (U) 16 May 1975. Classified SECRET.

(8) Personal Communication DRSAR-DAA, J. Hammond, 27 March 1979.

(9) DAPAM 700-16, The Army Ammunition Management System ODCSRA, February 1978.

(10) SB-38-26, "Ammunition Supply Rates" (U) 25 September 1972. Updated TWX Messages through Feb 1977, and known as official "D-77 Rates". Classified CONFIDENTIAL.

(11) NATO Glossary of Terms APP-6(0), April 1977.

(12) FM 100-10, Combat Service Report Handbook, October, 1968. Latest issue dated 30 April 1976.

(13) Procurement Planning and Policy Guidance, 1 December 1975. ODCSRDA, Washington, D.C. 20310.

(14) DESCOM Report No. K80BBY0244A, Class V In-Theater-Prepositioned Requirements (U), October 1978. Classified SECRET.

(15) OASD "Consolidated Defense Guidance on the FY 81-85 POM for Services" Section M Logistics Planning and Programing Guidance (U) date 9 Feb 1979 Classified SECRET. See also dated 13 Feb 1979 MEMO, DACS-PBC, Subject: Consolidated Guidance (PBC MEMO 79-42-A/SPC MEMO 79-4), Classified SECRET WORKING PAPERS.

(16) DESCOM Report No. K80BBY4604A, AR 11-11 "Weapons Density by Day" dated 26 Sep 1976 with updating amendments through March 1977.

(17) ODCSOPS (DAMO-FD) Structure and Composition System (SACS) File dated December 1978.

REFERENCES (CON'T)

(18) CTA-23-100. Series, "Common Tables of Allowance, Ammunition, etc. Training", July 1976.

(19) Materiel Annex of the Five Year Defense Plan.

(20) AR 710-8 "Nonnuclear Ammunition Combat Rates", 15 February 1975.

(21) FM 101-10-1 "Staff Officers Field Manual, Organizational Technical, a and Logistics Data", July 1976, C1, 10 Feb 1978, Chapter 3, "Class V Supply".

(22) DARCOM Logistics Planning and Programing.

(23) Handbook entitled, "ARRCOM's Management of Its Ammunition Plants" DRSAR-OP, September 1978.

(24) MAJ H. Bailey, DAMA-CSM, in AMMO Quarterly Review, December 1977.

(25) DARCOMR 700-5 "Logistics of Major Item Management", Sep 1978.

(26) AR 700-22 "Worldwide Ammunition Reporting System (WARS), CSGLD-1322 (RI) (MIN), 15 Oct 1976.

(27) HQDA, DAMA-CSM, "Army Ammunition Plan", October, 1978.

(28) U.S. Army War College Testbook, "Army Command and Management: Theory and Practice", Carlisle Barracks, PA, 1977-1978.

(29) AR 700-90 "Army Industrial Preparedness Program", C1, 1 April 1977.

(30) AR 700-120 "Materiel Distribution Management", C2, 21 February 1975.

<u>Memorandum for Record</u>

TDP'S OF $2500 AND LESS

(Response to DCG Note PE 667,

31 May 79)

Donald Eckman

DRSAR-PEL 6 Jun 79

MEMORANDUM FOR RECORD

SUBJECT: TDP's of $2500 and Less (Response to DCG Note PE 667, 31 May 79)

References:

. DCG Note PE 667, 31 May 79

. Open PWD's by PROC-PT AGE-DETAIL (PASS), 29 May 79

. Monthly G Series Back-Orders, 29 May 79

. DRSAR-PE, DF, 4 May 79, subj: Impact of Increased Lead Time for Secondary Items: A Cost Estimate for ARRCOM

Question:

" --- What happens to our readiness if R+D Commands only look at $2500 and up on TDP's?"

Conclusions:

In the analysis of the question we have found no evidence to support enhancement of our readiness position by incorporating the suggested change. On the other hand the guarantee of the quality of those TDP's for the approximately 55% of PRON's requiring new or updated TDP's should be assured prior to taking any such suggested action. In addition, we have, here and in previous studies, observed a related area in which improvements in efficiency may be forthcoming: replacing several PRON's of low value for the same item with one of larger value.

Discussion:

In determining the impact on readiness of not submitting requests for TDP's to design agencies for PRON's of value $2500 or less, the assumption was made that ARRCOM would have the facility to provide adequate TDP's for the approximately 55% of the PRON's in this category currently requiring new or updated TDP's.

The flow of TDP's was determined (see Figure 1) and the various residence times at current processing points were established using the current PASS Report (29 May 79). These were available as distributions (see Table 1 & 2) and by treating these as grouped data the mean times of residency were determined. If one can assume that these processes are stationary (i.e. the distribution of resident times do not change for the period of interest) we can utilize the PASS data to infer what would happen if the activity at the design agency were replaced by some other process providing an equivalent function.

In such a case we can see that if the 45 days residence for a TDP request at the design agency were replaced by an activity, providing the same results, which would take, say, only 7 days, the time for those PRON's to be available at procurement would be reduced by 38 days.

The question must then be asked: would such a savings have any effect on our readiness position? In addressing this question the Monthly G Series Back-Order Report of 29 May 79 was used as an indicator of our readiness position vis-a-vis our customer. If it can be shown that our current method of operations, with regard to the category of PRON's in question, do not contribute significantly to our back-order problem then any reduction in processing time could not be expected to have an impact. Using the data available from the PASS Report and Back-Order Report, we looked for NSN's on back-order for which a related TDP request was resident in a design agency.

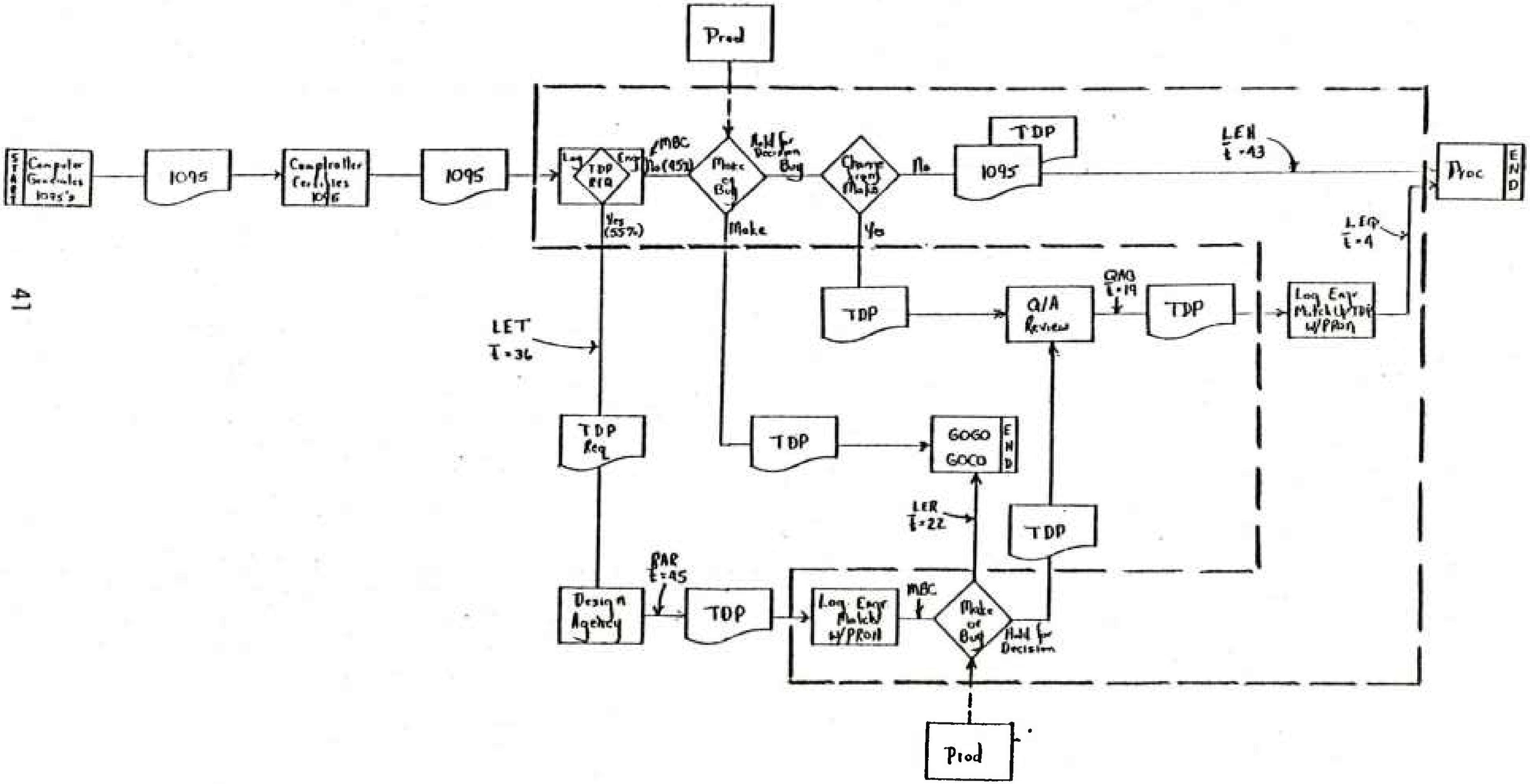
Of the 600 requests related to PRON's of value $2500 or less currently resident at ARRADCOM, MIRADCOM, TARADCOM, and CSL only three were found in which the related PRON's were for NSN's which were in the Back-Order Report. These are presented in Table 3 and are for very small quantities of minor parts, although two of them are coded priority 02. Of the three, only the counterweight used in the fire control system of the 30mm AA Gun is a weapon part. This would indicate that there is a very low, if not insignificant, relationship between back-orders and our current method of processing new or updated TDP's. Although we show no correlation for <u>current</u> back-orders and <u>current</u> TDP processing activity, this does not mean the back-orders could not have resulted from previous TDP activity or lack of activity.

In order to determine if there is some significant degree of correlation between the back-order position and TDP processing residence times, the problem should be subjected to time series analysis to determine if there are, in fact, leading or lagging factors present.

The difficulty in performing time series analysis and validating the assumption of stationary processes lies in the fact that data is retained for only three months. In the absence of an historical data base we proceeded with the analysis using current data as the best available. Our conclusions are presented in this context.

Figure 1
FIGURE 1: FLOW OF TDP ACTION FOR ARMY STOCK FUND

ave times ($\bar{t}$) for action ≤ $2500



DRSAR-PEL 6 June 79
SUBJECT: TDP's of $2500 and Less (Response to DCG Note PE 667, 31 May 79)

Related to the problem of the volume of PRON's with small values and the associated workload in "paper shuffling", an observation was made during interviews with Mr. R. Boyum of LET and also in previous investigations of ALT's by this office. It was observed that there appear to be a significant number of PRON's for the same NSN's and that many of these are for small values ($2500 or less). This can be corroborated by a review of an open PWD Listing.

Our investigations of Lead Times has also provided an indication of the impact on ARRCOM's funds and costs. A DF prepared by this office for MM (see ref) presented the added cost incurred due to the overall increases in Lead Times from 30 Sep 76 to 30 Sep 78, which are:

Increased Annual Holding Cost (@23% of assets on hand)	=	$0.9\bar{M}$/yr
Increased Annual Investment (@10%)	=	$5.9\bar{M}$/yr
Increased Annual Obsolesence Risk (8% of value on order)	=	$4.7\bar{M}$/yr
Total Increased Annual Cost		$11.5\bar{M}$/yr

ARRCOM would continue to incur this loss each year while continuing to operate at the higher levels of lead time. Therefore, any reduction in lead time would not only have a favorable impact on readiness but would lead to reduction in overall costs.

3 Incl
Tables 1, 2 and 3

Donald R Eckman
DONALD R. ECKMAN
Operations Research Analyst
Logistics Systems Analysis Division
Program Analysis & Evaluation Directorate

TABLE 1

NUMBER OF TDP'S IN DESIGN AGENCY DISTRIBUTION BY TIME AT AGENCY
(PASS 29 MAY 79)

LOCATION & FUNDING	PWD'S ≤$2500 ELAPSED TIME AT PROCESSING POINT (DAYS) 0-30	31-60	61-90	90-120	121-150	151-180	>180	≤2500 TOTAL	TOTAL *
ARRADCOM									
.PAA MJR									21
.PAA 2ND		3	1	1				5	37
.ASF	235	160	122	21	6	3	2	549	925
.TOTAL≤$2500	235	163	123	22	6	3	2	554	983
.TOTAL*	391	275	218	57	20	8	14	-	983
CSL									
.PAA MJR									4
.PAA 2ND									4
.ASF	10	6	17	5	1	2		41	88
.TOTAL≤$2500	10	6	17	5	1	2		41	96
.TOTAL*	25	12	43	10	2	2	2	-	96
MIRADCOM									
.PAA MJR									
.PAA 2ND	1							1	1
.ASP		1						1	1
.TOTAL≤$2500	1	1						2	2
.TOTAL*	1	0	1					-	2
TARADCOM									
.PAA MJR									
.PAA 2ND									
.ASF	1	1			1			3	7
.TOTAL≤$2500	1	1			1			3	7
.TOTAL*	5	1	0	0	1			-	7
TOTAL									
.PAA MJR									25
.PAA 2ND	1	3	1	1				6	42
.ASF	246	168	139	26	8	5	2	594	1014
.TOTAL≤$2500	247	171	140	27	8	5	2	600	1018
.TOTAL*									

*Unconstrained by Dollar Amount

TABLE 2

NUMBER OF TDP'S IN DRSAR-LE
DISTRIBUTION BY TIME AT PROCESSING POING
(PASS 29 MAY 79)

	1-30	31-60	61-90	91-120	121-150	151-180	>181	TOTAL ≤2500	TOTAL *
LEH: (Duplicate Procurement Actions for which a TDP was previously requested.)									
.PAA MJR	1							1	2
.PAA 2ND									4
.ASF	15	18	10	4	1			48	93
.TOTAL≤2500	16	18	10	4	1			49	99
.TOTAL*	34	34	23	6	1	1		-	99
LEQ: (Returned to DRSAR-QA)									
.PAA MJR									1
.PAA 2ND									2
.ASF	8							8	20
.TOTAL≤2500	8							8	23
.TOTAL	20	3						-	23
LER: (TDP Received from Design Agency & DRSAR-LE Processing.)									
.PAA MJR	1							1	7
.PAA 2ND		1						1	11
.ASF	77	14	4	1				96	175
.TOTAL≤2500	78	15	4	1				98	193
.TOTAL	156	28	8	1	0	0	0	-	193
LET: (Action from DRSAR-CP)									
.PAA MJR									14
.PAA 2ND			1					1	17
.ASF	77	23	9	1				110	226
.TOTAL ≤2500	77	23	10	1				111	257
.TOTAL*	173	60	22	1	1			-	257

*Unconstrained by Dollar Amount

TABLE 3

ITEMS ON G-SERIES B/O AS OF 29 MAY 79 FOR WHICH TOP IS AWAITING IN DESIGN AGENCIES
(PER PASS 29 MAY 79)

NSN PRON REQ #	U/M - QUANTITY	- PRON COST($) U/C($)	FIACD - ANLCO	- - PRIORITY CO	ACCRURED ALT PWO STATUS DAYS IN DESIGN AGENCY	TDO - COMP GEN REG-DEL-DT	
4940001660016 M1904388M101 WK4FY09078G125	EA - 10	- 1000.00 0.10	M22L5 NM304 -	- - 02	47 30 31/60	79 May 31 - 79 Mar 30	Other Weapon Categories Misc Maint & Repair Shop SP EQP FSN4940 No Nomenclature
1285010700997 M1904293M101 WK4F879071G231	EA - 1	- 1212.75 24.75	M22KL NJ40A -	- - 02	50 34 31/60	79 Nov 12 - 79 Mar 23	Gun Anti-Aircraft 20mm SP Fire Control FSN1285 Counterweight
4931010100165 M1903155M101 B1SA4V8182G966	EA - 1	- 1030.00 206.00	M22LZ NM300 -	- - 03	78 30 31/60	79 May 08 - 78	Other Weapon Categories Fire Control Maint & Repair Shop SP EQP FSF4931 Adapter, Card Checker

Memorandum for Record

OBSERVATIONS ON ALTERNATIVE METHODS FOR CALCULATING EVAPORATION RATES FROM CHEMICAL AGENT SPILLS

George Schlenker

DRSAR-PEL 7 June 1979

MEMORANDUM FOR RECORD

SUBJECT: Observations on Alternative Methods for Calculating Evaporation Rates from Chemical Agent Spills

1. References.

a. DF, DRSAR-LEC to DRSAR-PE, 26 Dec 78, subject: Chairman for Technical Advisory Group -- DDESB Technical Paper No. 10.

b. Letter, DRCPM-DR-T, 7 Nov 78, subject: Recommendation for Change to DDESB Technical Paper No. 10.

c. Technical Paper No. 10, Change 2, DDESB, Nov 77, title: Methodology for Chemical Hazard Prediction.

d. Technical Paper, Office of the PM for Chemical Demil and Installation Restoration, title: Calculation of Evaporation Rates for Chemical Agent Spills.

2. Background.

Ref a formalizes a request to DRSAR-PE to provide a technical review of alternative methods for calculating the rate of evaporation of liquid chemical (agent) spills. The original request for evaluation is contained in the Ref b letter. This letter indicates an alternative method to that contained in Ref c (the present standard methodology - TP10). The alternative is described in the Ref d technical paper.

3. Accordingly, this memorandum provides a detailed review of Ref d and compares the proposed method contained therein for calculating evaporation rates from liquid spills into moving air with TP 10 (Ref c). However, before plunging into the mathematical details, a brief summary of the comparison is provided next.

4. Executive Summary.

Both the standard method for calculating evaporation rates of liquid agent spills (Ref c) and the alternative proposed in Ref d are fundamentally semi-empirical, relying on a limited set of measured

evaporation rates from selected liquids to choose a suitable mathematical form to fit the parameters.

5. When the equations for each of these methods are manipulated to yield the evaporation rate as a function of the same variables very nearly identical functional forms are obtained. For example, in both cases the evaporation rate per unit area into moving air is shown to be proportional to the Schmidt number to the -2/3 power, to be proportional to the wind speed to the (nearly) 0.8 power, to be proportional to the agent molecular weight, and to the agent vapor pressure. Differences appear in the dependence of evaporation rate upon temperature and upon dimensions of the puddle. Additionally, there is a difference in proportionality constants so that the standard (Ref c) method yields a smaller evaporation rate than that of Ref d for the same situation.

6. For environmental conditions near ambient and moderate surface winds speeds of 1 to 4 m/s, the evaporation rate per unit area given by TP 10 (Ref c) is about 3/4 of that calculated by Ref d. The factor relating the alternative unit evaporation rates varies with the environmental conditions but is essentially independent of the agent selected, being between 0.73 and 0.80 for the numerical examples given in Ref d. Thus, within the errors expected in the input data, the two methods would yield essentially the same result if the value given by TP 10 were increased by about 30%.

7. It is unfortunate that the author of Ref d did not explicitly display the experimental bases upon which each model rests. If that had been done one might be able to judge the fidelity of both models to a common set of pertinent experiments. Lacking this one can only say that presently there is scant basis for preferring one method over the other insofar as evaporation into moving air is concerned. With respect to evaporation into still air, TP 10 is not phenomenologically accurate at wind speeds approaching zero so that an alternative which approximates the evaporation rate data for still air is clearly to be preferred in this instance.

8. Comments on Ref d--Calculation of Evaporation Rates. In reviewing Ref d I was disturbed by several aspects of the presentation which made interpretation difficult. These problems are cited here with the hope that a final, improved version of the technical paper can be produced. Among the problems are the following:

a. Frequent failure to define variables when (or before) they are used in the text. An example is the group of variables $\mu/(\rho D)$ known as the Schmidt number, in which μ and ρ are the viscosity and density of the vapor and D is the molecular diffusivity of the vapor into air. As far as can be determined D was not explicitly defined anywhere.

b. The paper is careless in the treatment of units. Examples are the absence of units for the variables in equations (4) and (5). Additionally, there is no consistent system of units employed. The wind speed u is presented and used in (m/s) whereas the c.g.s. system is employed elsewhere. Additionally lengths are given in (m). This necessitates conversion factors such as the 10^2 found in (4), p. 4 and appears to be responsible for the errors in expressions for viscosity and Reynold's number found at the bottom of p. 5.

c. Different notation is used for the same variable. An example is that VP in (5) stands for vapor pressure of the evaporating liquid whereas P_v is used for the same variable in (14) (with a change of units from mm Hg to atm). Another example of inconsistent notation is the use of M in (5) and M_L in (14) for the gram molecular weight of the agent.

d. During a mathematical development certain equations are presented which are irrelevant to the principal objective of the development. Examples are equation (2), p. 4, and the equations on pages 9, 10, and 11 concerned with the time rate of change of temperature of the liquid agent. These are not used in or related to subsequent results concerning evaporation rates.

9. Mathematical Relations for Calculating Evaporation Rates.

In the following developments the evaporation rate per unit area for TP 10 (E_1) is compared with the alternative result (E_2) presented in Ref d. These results will apply when the c.g.s. system of units is applied as indicated. Our goal is to reveal the similarity of these methods.

10. As presented in Ref d, the technique of TP 10 for calculating the unit evaporation rate of the spilled agent is contained in equations (3), (4), and (5) of Ref d. These equations are:

$$E_1 = 0.001262\ u\rho M p_v\ Re^{-0.2}\ Sc^{-2/3}, \tag{1}$$

with

E_1 evap. rate per unit area ($gm/cm^2/s$)

u wind speed (cm/s)

M mol wt of agent (gm mol/mol)

p_v vapor pressure of agent (atm)

ρ density of air (vapor) (gm/cm^3)

Re Reynolds number (numeric)

Sc Schmidt number (numeric)

and with the auxiliary relations:

$$\rho = 0.3487/T \qquad (gm/cm^3) \tag{2}$$

with T in (deg K).

$$\mu = 10^{-6} \exp(4.36 + 0.002844T) \quad , \tag{3}$$

the viscosity of the vapor (essentially air) (gm/cm/s) .

$$Re = Lu\rho/\mu \tag{4}$$

with L the effective length (cm) of the spill in the direction of surface wind.

$$Sc = \mu/(\rho D) \tag{5}$$

with D the molecular diffusivity of the agent (cm^2/s) at the temperature of the agent. The other variables have the dimensions given above.

11. <u>Example 1.</u>

The above equation (1) is evaluated with sample data provided in Ref d, example 1. Let

$u = 100$ (cm/s)

$M = 140.1$ (gm/mol) for agent GB

$T = 293$ (°K)

$p_v = 2.15/760 = 2.83\ 10^{-3}$(atm)

$\rho = 1.19\ 10^{-3}$ (gm/cm^3)

$\mu = 1.80\ 10^{-4}$ (gm/cm/s)

$L = 173.2$ (cm) with a square puddle

$D = 6.94\ 10^{-2}$ (cm^2/s) at 20°C.

From these data and using (4) and (5),

$$Re = 1.145\ 10^5$$

$$Sc = 2.18 \quad .$$

Thus, from (1),

$$E_1 = 3.446\ 10^{-6}\ (gm/cm^2/s).$$

In the units of Ref d,

$$E_1 = 2.067\ (gm/m^2/min),$$

which agrees with the calculated value of Ref d.

12. A rearrangement of (1) using the auxiliary relations will prove interesting. To facilitate comparison with the alternative unit evaporation rate presented in Ref d, the Reynolds number will be written using (4) above.

Thus,

$$Re^{-0.2} = \mu^{0.2}\ L^{-0.2}\ u^{-0.2}\ \rho^{-0.2} \quad . \qquad (6)$$

With (1) and (6),

$$E_1 = 1.262\ 10^{-3}\ \mu^{0.2}\ L^{-0.2}\ u^{0.8}\ \rho^{0.8}\ Sc^{-2/3}\ M\ p_v \qquad (7)$$

From (3) one observes that viscosity of the air is relatively weakly dependent upon temperature, being approximately

$$\mu^{0.2} \cong 0.151\ (1 + 5.688\ 10^{-4}\ T).$$

Therefore, replace $\mu^{0.2}$ in (7) with its value at a temperature of $293^\circ K$ -- 0.1783 (gm/cm/s).

Additionally, replace $\rho^{0.8}$ in (7) with a result obtained from (2) --

$$\rho^{0.8} = 0.4305\ T^{-0.8},$$

obtaining

$$E_1 \cong 9.68710^{-5}\ Sc^{-2/3}\ L^{-0.2}\ u^{0.8}\ T^{-0.8}\ M\ p_v \quad . \qquad (8)$$

For a circular puddle, the effective length L is $\sqrt{\pi/4}\ x_o$, with puddle diameter x_o. In terms of x_o, (8) becomes

$$E_1 \cong 1.0166\ 10^{-4}\ Sc^{-2/3}\ x_o^{-0.2}\ u^{0.8}\ T^{-0.8}\ M\ p_v \quad . \qquad (9)$$

13. An alternative expression for unit evaporation rate given by equation (14) of Ref d is

$$E_2 = 2.689\ 10^{-4}\ Sc^{-0.67}\ x_o^{-0.11}\ u^{0.78}\ T^{-1}\ M\ p_v, \qquad (10)$$

with the variables having the same units as employed above. Using the data of example 1 but treating the spill as a circle of the same area, equation (10) yields $E_2 = 4.388\ 10^{-6}$ (gm/cm^2/s) or 2.633 (gm/m^2/min), in agreement with Ref d. For this example $E_1/E_2 \cong 0.78$.

14. The most conspicuous functional difference between E_1 and E_2 shows

$$E_1 \propto x_o^{-0.2}\ T^{-0.8} \quad ;$$

approximately, whereas

$$E_2 \propto x_o^{-0.11}\ T^{-1.0} \quad .$$

Dependence upon the other variables is nearly the same. In most instances of practical concern, this comparison means that E_1 is smaller than E_2 by a factor of about 3/4. Because of the semi-empirical nature of both E_1 and E_2, it is questionable which is the more correct. However, for both formulas information about the agent, which is contained in Sc, M, and p_v, appear in the same functional form. Thus, the formulas are differentially sensitive only to environmental factors.

George J. Schlenker

GEORGE SCHLENKER
Operations Research Analyst
Logistics Systems Analysis Division
Program Analysis & Evaluation Directorate

NO. OF COPIES	DISTRIBUTION LIST
1	HQDA(DAMO-ZA) WASH DC 20310
1	HQDA(DAMA-CSZ-A) WASH DC 20310
1	HQDA(DALO-SMZ) WASH DC 20310
	Commander US Army Materiel Development and Readiness Command
1	ATTN: DRCRE
1	DRCPA-S
	5001 Eisenhower Avenue Alexandria, VA 22333
	Commander US Army Armament Materiel Readiness Command
1	ATTN: DRSAR-CG
1	DRSAR-DCG
1	DRSAR-LC
1	DRSAR-LE
1	DRSAR-LEP-L (Tech Lib)
1	DRSAR-CP
5	DRSAR-PE
1	DRSAR-DA
1	DRSAR-PC
1	DRSAR-PD
1	DRSAR-IR
1	DRSAR-OP
1	DRSAR-QA
1	DRSAR-IS
1	DRSAR-MA
1	DRSAR-MM
1	DRSAR-AS
1	DRSAR-SF
	Rock Island, IL 61299
1	Commander US Army Materiel Development and Readiness Command Washington Field Office ATTN: DRSAR-AA 5001 Eisenhower Avenue Alexandria, VA 22333
	Commander US Army Armament Research and Development Command
1	ATTN: DRDAR-SEA
1	DRDAR-SCS-M
1	DRDAR-LCS-E

NO. OF COPIES	DISTRIBUTION LIST (Cont)
1	Commander US Army Development and Readiness Command Office of the Project Manager for Selected Ammunition ATTN: DRCPM-SA Dover, NJ 07801
1	Project Manager for M110E2 ATTN: DRCPM-M110E2 Rock Island, IL 61299
1	DIVAD Manager Logistic Support Office ATTN: DRCPM-ADG Rock Island, IL 61299
1	Product Manager for Production Base Modification and Expansion ATTN: DRCPM-PBM Dover, NJ 07801
1	Product Manager for Advanced Attack Helicopter Systems US Army Aviation Systems Command St. Louis, MO 63166
1	Product Manager for AH-1 Cobra Series Aircraft US Army Development and Readiness Command P.O. Box 209 St. Louis, MO 63166
1	Commander Rock Island Arsenal ATTN: SARRI-CO Rock Island, IL 61299
1	Commander Watervliet Arsenal ATTN: SARWV-CO Watervliet, NY 12189
1	Commander Human Engineering Laboratories ATTN: DRXHE-D Aberdeen Proving Ground, MD 21005
	Director US Army Materiel Systems Analysis Activity
1	ATTN: DRXSY-D
1	DRXSY-MP (Mr. Cohen)
	Aberdeen Proving Ground, MD 21005

NO. OF COPIES	DISTRIBUTION LIST (Cont)
1	Commander US Army Communications and Electronics Materiel Readiness Command ATTN: DRSEL-PL-SA Fort Monmouth, NJ 07703
1	Commander US Army Electronics Research and Development Command ATTN: DRDEL-ST-SE Adelphi, MD 20783
	Commander US Army Missile Command
1	ATTN: DRSMI-D
1	DRSMI-DS (R&D)
	Redstone Arsenal, AL 35809
1	Commander US Army Communications Research and Development Command ATTN: DRDCO-PPA-SA Fort Monmouth, NJ 07703
1	Commander US Army Operational Test and Evaluation Agency ATTN: CSTE-ED 5600 Columbia Pike Falls Church, VA 22041
1	Commander US Army Tank-Automotive Materiel and Readiness Command ATTN: DRSTA-S Warren, MI 48090
1	Commander US Army Tank-Automotive Research and Development Command ATTN: DRDTA-V Warren, MI 48090
1	Commander US Army Troop Support and Aviation Materiel Readiness Command ATTN: DRDAV-BC P.O. Box 209 St. Louis, MO 63120
1	Project Manager for Cannon Artillery Weapons Systems ATTN: DRCPM-CAWS Dover, NJ 07801

NO. OF COPIES	DISTRIBUTION LIST (Cont)
1	Commander US Army Mobility Equipment Research and Development Command ATTN: DRDME-O Fort Belvoir, VA 22060
1	Commandant US Army Field Artillery Center Fort Sill, OK 73503
1	Commandant US Army Infantry School Fort Benning, GA 31905
1	Commander US Army Missile and Munitions Center and School Redstone Arsenal, AL 35809
1	Commandant US Army Air Defense School Fort Bliss, TX 79916
1	Director US Army Management Engineering Training Agency ATTN: DRXOM-QA Rock Island, IL 61299
2	Director US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL (Tech Lib) White Sands Missile Range White Sands, NM 88002
1	Director Advanced Research Projects Agency 1400 Wilson Boulevard Arlington, VA 22209
1	Commander Defense Logistics Studies Information Exchange Fort Lee, VA 23801
1	Commander US Army Logistics Center ATTN: ATCL-S Fort Lee, VA 23801
1	Director US Army Materiel Development and Readiness Command Ammunition Center ATTN: SARAC-DO Savanna, IL 61074

NO. OF COPIES	DISTRIBUTION LIST (Cont)
1	Commander Technical Escort Unit Aberdeen Proving Ground, MD 21010
1	Commander US Army Test and Evaluation Command ATTN: DRSTE-SY Aberdeen Proving Ground, MD 21005
12	Defense Documentation Center Cameron Station Alexandria, VA 22314